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Comparative Study of River Benue and River Asa Sand in North Central Nigeria as Filter Media

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Abstract

This study investigated the comparative use of sands from River Benue at Makurdi and River Asa at Ilorin Kwara State in North- Central Nigeria as filter sands in water treatment. Sand is mostly widely employed as the porous substance (Filter Medium) in filtration plants all over the world and in Nigeria. The sands were subjected to various soil mechanics and hydraulic tests including particle size distribution, specific gravity, acid solubility, porosity, permeability and filterability. The study investigated the physical, chemical and filtration properties of these River sands (local sands) as filter media for water treatment, to determine their filtration performance. The study showed that the local sand from the rivers have effective sizes (Es) of 0.35 mm and 0.40 mm; uniformity coefficient (Uc) of 1.43 and 1.25; acid solubility (%) of 1.05 and 2.10; Specific Gravity of 2.67 and 2.29; Porosity (%) of 42 and 51; permeability (cm/sec) of 4.7×10^{-1} and 1.06 for River Benue and Asa respectively. However, that of the imported sand from Brazil used as control has effective size (Es) of 0.46 mm; uniformity coefficient (Uc) of 1.48; acid solubility (%) of 0.85; specific gravity of 2.60; porosity (%) of 45; permeability (cm/sec) of 3.5×10^{-1}. The maximum head loss obtained for the river sands (local sands) and imported sand from Brazil which was used as control with hydraulic loading rates of 6.45 m/hr and 9.65 m/hr at 16 and 13 hours of filter run time were (11.294, 19.014 and 11.281) cm and (14.467, 24.347 and 14.454) cm of water for River Benue, Asa and imported sand from Brazil respectively.

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The results obtained for filter quality of both the Local sands and Imported sand from Brazil which was used as control with turbidity of 32 NTU and 38 NTU and hydraulic loading rates of 6.45 m/hr and 9.65 m/hr at 16 and 13 hours of filter run times were (2.01, 5.09 and 1.13) NTU and (2.79, 5.87 and 2.12) NTU respectively, which were well below the recommended value of 5.0 NTU standard, except that of Asa River in both cases, which is above the recommended standard. Also, the percentage turbidity removal of the local sands and imported sand under the stated conditions were (93.72, 84.09 and 97.03) % and (91.28, 81.66 and 94.42) % respectively. At backwashing rate of 45.9 m/hr, the expansion rate of sand from River Benue, Asa and the imported sand were (25.83, 56.67 and 22.50) % which were within the recommended expansion of (20 – 50) %. At the end of the study, it was found that, sands from river Benue had similar properties with that of the imported sand from Brazil and this can be used as a substitute for imported sand (as filter media) in water treatment plants while River Asa sand cannot be used as filter media due to its properties were not up to standard as a filter media.

Keywords: Local Sands; Soil Mechanics; Hydraulic Test and Filtration.

1. Introduction

Sand filtration is an integral part of most drinking water treatment facilities. This includes both large technologically advanced treatment plants serving relatively affluent urban areas and small plants serving poor communities in relatively isolated rural areas. Sand filtration is usually the final (and in some cases the only) particle removal step in the water treatment and plays a critical role in safeguarding the macro and micro particulate quality of the finished water as well as in reducing disinfectant requirement [1]. Studies have shown that filters can be effective in removing iron, manganese and organics, Organics can form carcinogenic by-products when they react with disinfectants [2].

Water filtration is a physical process for separating colloidal impurities from water by passage through a porous medium, usually a bed of sand or other granular material like rice husk, gravel and anthracite [3]. As water percolates slowly through the filter medium (Sand), natural physical, biological and chemical processes combine to provide treatment.

Over the years, various complex ways have been devised by men who are either complementary or supplementary to each other, in order to make raw water potable. The processes are collectively referred to as the water treatment processes with sections, like sedimentation, coagulation, filtration, disinfection, softening and aeration among others [4]. These treatment processes has been satisfactorily established and adopted in all the developed countries of the world and most urban centres of developing countries. However, the adoption of this technology for the growing populations of the developing world (rural areas to be specific) is becoming a challenging task [5]. Because of the imposed constraints due to paucity of financial resources coupled with the non-availability of skilled technical personnel and sophisticated equipment, two options are evident namely: new water treatment methods have to be evolved or the existing one modified. The main goal is the development of a water treatment unit, which is cheap, simple and easy to construct, maintain and operate. The units should not require either the incorporation of sophisticated equipment or the need for skilled technical labour [6].

Among the various unit operations of a conventional water treatment plant, filtration occupies a central and important place and perhaps the oldest and most widely used in the water purification treatment [7].

The filtration process involves the removal of suspended particles, colloidal materials, micro-organism like bacteria and other particulates, a combination of hydraulic and mechanical straining processes. Basically the process of filtration consists of passing the water through a bed of sand, or other suitable medium, at low speed [8]. In order to achieve the final degree of clarity, the influent water from the settling basins must be of fairly low turbidity. The degree of settling may vary with the type of filter adopted. Filtration is most effective when used as a final treatment process after the use of sedimentation and/or coagulation, and can be loosely classified as pre-coat filtration or depth filtration. The former involves the use of particulate coating on thin materials supporting media such as cloth or finely woven wire while the latter utilizes a permanent, relatively thick medium usually granular, of varying porosity and density.

Depth filtration is of greater significance in water and wastewater treatment. It utilises such media as sand, anthracite coal, resin, and some local materials. However, sand is mostly used in graded form though the recent practice involves the use of multi-media filters, where two or more of the above materials are combined [9]. A primary factor in choosing filter materials is its resistance to abrasion. This is a major factor during back washing. Sand are usually used as filter media in the following filters, namely: Rapid sand, Pressure, Slow sand, simple domestic, Intermittent sand filter etc. The efficiency of filtration depends largely on the filter media. Filter media are officially standardised when the traditional sand laid over gravel is used or finely crushed anthracite coal or mixed media of the above or diatomaceous earth is used [10].

Filter performance depends on the design, the mechanisms involved in removal of suspended solids during filtration and the operation of the filter, physico-chemical pre-treatment and the efficiency of the media between filter runs [11].

When using sand as a filter medium, composition, size, uniformity and depth of the medium all affect the sand filter performance. Characteristics of the media composition, such as its solubility, acidity, and hardness, must be considered in the filter design. It is extremely important that the medium be washed. The media component should be inspected for cleanliness and suitability by a qualified individual before it is used in the filter. The media grains are sorted and sieved through a series of mechanical sieves. The grains must be relatively uniform in size to prevent clogging. “Effective size” and “uniformity coefficient” are measurements used to express these characteristics. Each sand filter type has its own particle size range requirements. Uniformity coefficient of four or less is recommended for all filter media [12]. Reference [13] Stated that media should neither be too coarse nor too fine. Coarse media allow water to pass through the filter quickly without receiving adequate treatment, while on the other hand very fine media slows down treatment, is prone to clogging and can keep oxygen from reaching certain parts of the filter.

2. Materials and Methods

2.1 Sample Collection and Preparation

Two (2) sand samples for the study were collected from the two Rivers describe Makurdi and Ilorin. Samples were collected at three locations (Sample Points) from the top of the river bank, the bed of the rivers and at depth of $2\frac{1}{2}\ meters$ from the river banks with a shovel into porous sacks, so as to allow the water to drain easily with their co-ordinates shown as shown in Table 1. These were mixed together as composite samples (Stocks). The collected sand samples were thoroughly washed to remove all organic materials, dirt and rubbish that may be present in the sand samples.

The sand samples were packed in sacks after washing for dewatering, after which they were removed from the sacks and spread on a clean surface for sun drying. After drying the samples were stored in sacks.

Table 1: River Sands Showing Sample Collection Points and Co-ordinates

River Sands	Sample Points	Co-ordinates
	1	7°46'9.07" N 8°22'41.10" E
Benue	2	7°44'48.27" N 8°30'48.91" E
	3	7°44'14.80" N 8°39'22.20" E
	1	8°27'0.12" N 8°26'46.48" E
Asa	2	8°26'46.56" N 4°33'21.61" E
	3	8°26'33.15" N 4°33'16.74" E

2.2 Site description

(a) River Benue

River Benue in West African, originated from Northern Cameroon and flowing West across Nigeria, lies on latitude $7^{o}33^{'}00^{"}N - 7^{0}57'00''N$ and longitude $8^{0}21^{'}00^{"}E - 8^{0}39'00''E$ and is the chief tributary of River Niger of length 1400 km. The river divides the state capital into two; the North and South banks which are connected by two bridges: the railway bridge and the dual carriage way bridge as shown in Figure1.

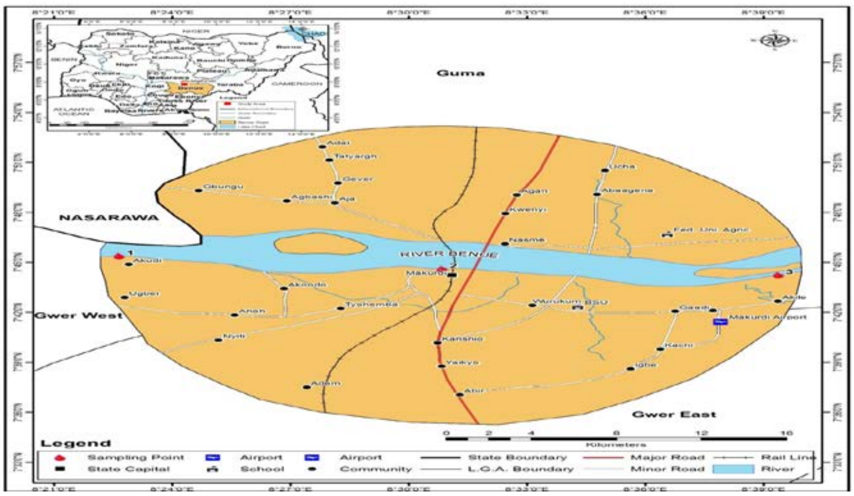

Figure 1: Map of Makurdi LGA showing River Benue with sample collection points

Source: Adapted and modified from Administrative map of Benue State 2014.

(b) River Asa

Asa River is one of the major rivers in Kwara State with much sand deposits. It lies between latitudes $08^0 26'00''N - 08^0 36'00''N$ and longitudes $04^0 26'00''E - 04^0 36'00''E$ within Asa and Ilorin West Local Government in Kwara State. It is located at the boundary of the south-western part of the state and is surrounded by Moro Local Government to the north, Oyun and offa Local Government to the south and Ilorin west Local Government to the East. The river originated its sources from River Niger and flows through Asa Local Government Area of Kwara State as shown in Figure 2.

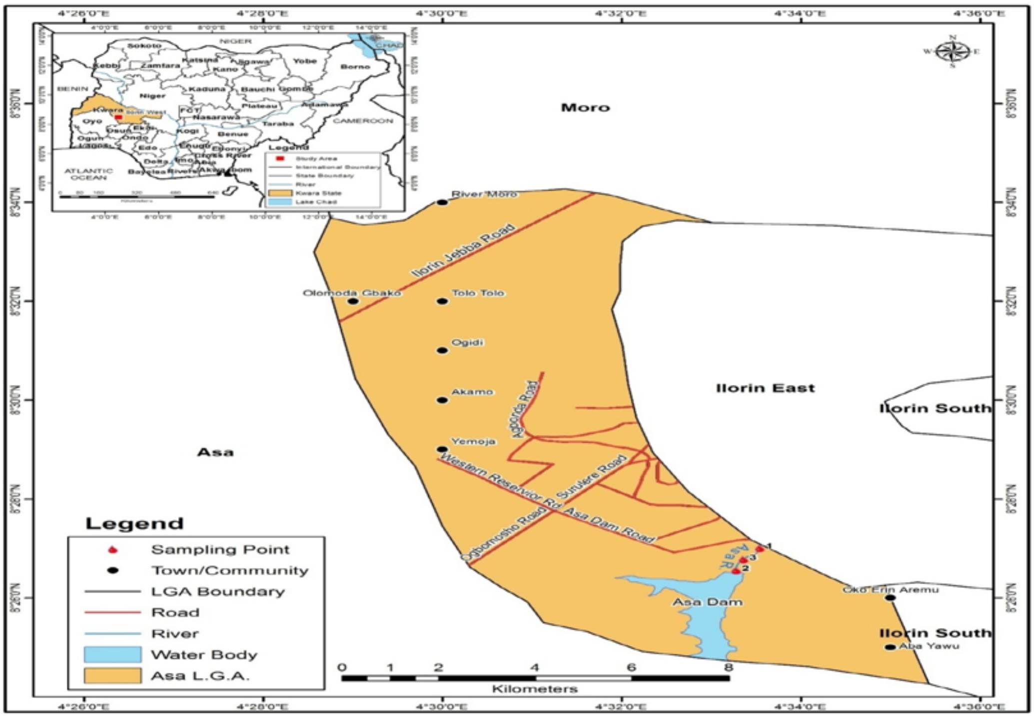

Figure 2: Map of Ilorin West LGA showing River Asa with sample collection points

Source: Adapted and modified from Administrative map of Kwara State 2014

2.3 Determination of particle size distribution

Apparatus

- Complete set of Sieves (Standard British Series)
- Electronic weighing balance, G & G, J.J 3000Gallenkamp Ltd
- Sacks, Dangote Sacks, 50kg, Nigeria
- Mechanical Shaker

These parameters was determined by sieve analysis using the method of the American Society Testing and

Materials [14] in which 500 grams of sand sample was sieved using standard sieves series (Apertures 4.760 mm, 2.360 mm, 2.000 mm, 0.600 mm, 0.425 mm, 0.300 mm, 0.212 mm, 0.150 mm and 0.075 mm). The sieves were arranged in decreasing sieve bore size from top to bottom as listed above. The weight of sand retained on each sieve was determined using the electronic weighing balance and the percentage by weight, passing through each sieve was determined and this was plotted against sieve size on a semi-logarithmic paper. The sieve size that permits 10 % by weight of the sand sample, to pass through (as interpolated from the plot on the semi-logarithmic paper) gives the Effective size **(Es)** of the sand sample. Similarly, the sieve that permits 60 % of the sand sample by weight, to pass through was obtained. The uniformity coefficient **(Uc)** of the sand sample was then determined [15] using the relationship below;

$$\text{Uniformity coefficient } (\mathbf{Uc}) = \frac{d_{60}}{d_{10}} \quad (1)$$

$$\text{Percentage passing } (\mathbf{\%}) = \frac{100(W_1 - W_2)}{W_1} \quad (2)$$

Where

W_1 is the initial weight of the sand

W_2 is the retain weight of the sand

d_{10} is the sieve sizes that pass 10 % of the medium

d_{60} is the sieve sizes that pass 60 % of the medium [15].

The percentage useable, too fine or too coarse filter media for a given effective size and uniformity coefficient are computed as:

The percentage usable (P_u), from $d_u = 2\ (d_{60} – d_{10})$

The percentage fine (P_f), $d_f = d_{10} – 0.2\ (d_{60} – d_{10})$

The percentage Coarse (P_c), from $d_u = d_{10} + 1.8\ (d_{60} – d_{10})$

2.4 Specific gravity determination

Apparatus

- Electronic weighing balance, G & G, J.J 3000Gallenkamp Ltd
- Hot Air Oven (Gallenkamp, BRIT.No.882942 ENGLAND)
- Mettler analytical balance capable of weighing accuracy $\pm$ 0.01gram, Mettler P160N
- Hand glove, C456, Agary Limited, Malaysia

Glassware

- Specific gravity bottles, Technico-England.
- Funnel (100 mm), Boro Silicate $24/20$ England

Specific gravity is mass per unit volume and is important because it affects the backwash flow requirements for the medium. It is determined using American Society Testing and Materials [16].

The weight **(W_1)** of specific gravity bottle was determined. The specific gravity bottle was filled with sand sample and combined weighted **(W_2)** determined. The specific gravity bottle with the sand sample was then filled with water and weight **(W_3)**. The water in the specific gravity bottle was drained. Water was filled in the specific gravity bottle weighed to give **(W_4)**.

The Specific gravity was then calculated using the formula in equation 3, developed by [17]

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \qquad (3)$$

2.5 Acid solubility

Apparatus

- Electronic weighing balance, G & G, J.J 3000Gallenkamp Ltd
- Hot Air Oven (Gallenkamp, BRIT.No.882942 ENGLAND)
- Mettler analytical balance capable of weighing accuracy $\pm$ 0.01gram, Mettler P160N
- Hand glove, C456, Agary Limited, Malaysia
- Crucible dishes, BS 34267, Gallenkamp England.

Glassware

- Measuring cylinder, Kinax USA (100 ml, 200 ml and 250 ml capacity)
- Glass beakers, Boro-Slicate England (100 ml and 200 ml capacity)

Reagents

- Sulphuric acid (H_2SO_4)
- hydrochloric acid (HCL), BDH Pool Limited England and
- Distilled Water

Acid solubility is used to express the proportion of carbonates or Hydrogen carbonates in the sample. A method recommended by [18] was adapted in the determination of the acid solubility of the soil sample. Four hundred (400) grams of sand sample were taken from the washed stock and recorded **(W_1)**. The weighed sample was then immersed in 40% (by volume) of hydrochloric acid (HCL) + 60% distilled water for 24 hours (1 day) in a plastic bucket, to dissolve any organic matter present in the sample. The sample was then filtered with the aid of filter paper and funnel to collect the residue (sand sample). The residue collected were properly rinsed with distilled water, oven dried for 2 hrs at 105 ℃ and weighed **(W_2)** to determine the loss in weight.

The percentage Solubility was then calculated as follows:

$$\% \text{ Solubility} = \frac{W_1 - W_2}{W_1} \times 100 \qquad (4)$$

Where:

W_1 = Intial weight of sand sample

W_2 = Final weight of sand sample

$W_1 - W_2$ = Loss in weight of sand sample

2.6 Determination of porosity of sand

Apparatus

- Electronic weighing balance, G & G, J.J 3000Gallenkamp Ltd
- Hot Air Oven (Gallenkamp, BRIT.No.882942 ENGLAND)
- Mettler analytical balance capable of weighing accuracy ± 0.01gram, Mettler P160N
- Hand glove, C456, Agary Limited, Malaysia
- Stop watch, HF Instrument, New York USA

Reagents

- Distilled Water

Porosity **(n)** is the ratio of void volume to the total bed volume, expressed as a decimal, fraction or percentage. It affects the backwash flow required, the fixed bed head loss, and the solid holding capacity of the medium. The porosity was determined in accordance with ([15], [19]).

A transparent tube of 38 mm and 750 mm was half-filled with water. 150g of sand sample was weighed and placed in the tube. Air and dirt was removed from the sand sample by shaking the tube. The dirty water in the transparent tube was decanted and the process was repeated until the sand sample is clean as evidenced by the quality of decanted water. The transparent tube was then filled with water and stopper with a cork, which was kept tight. The tube and its contents were supported by means of a clamp on a retort stand. The tube was agitated by inversion and allowed to settle freely in the water with no compaction or undisturbed. After settling, the level of sand in the tube column was then measured immediately, using a scale rule, after the last particles were observed to have settled. The volume **(V)** of the settled sand was then computed from the height of the sand in the column and the diameter of the tube.

Porosity of the sand was calculated as follows:

$$\text{Porosity } (\%) = \frac{Volume\ of\ Void}{Total\ Volume} \tag{5}$$

$$n\,(\%) = \frac{V - {}^{w}/_{\gamma}}{V} \times 100 \tag{5a}$$

Where:

γ is the specific gravity of sand sample.

w is the mass of sand sample used.

V is the volume of the settled sand in the column.

2.7 Permeability determination

Apparatus

- Electronic weighing balance, G & G, J.J 3000Gallenkamp Ltd
- Hot Air Oven (Gallenkamp, BRIT.No.882942 ENGLAND)
- Mettler analytical balance capable of weighing accuracy $\pm$ 0.01gram, Mettler P160N
- Hand glove, C456, Agary Limited, Malaysia
- Stop watch, HF Instrument, New York USA
- ICW laboratory permeameter (Eiji kelkamp Agrisearch No. 09 02)
- Brass Mesh

Reagents

- Distilled Water

Permeability test was determined using the Constant head test of [19]. The permeability was measured by the constant head method, using the I C W laboratory permeameter (Eiji Kelkamp Agrisearch No. 09 02). The equipment operates on the principle that water is cause to flow through a saturated sand column of know length **(L)** by the pressure difference on both sides of a well saturated sand sample.

The caps from the ring of known area **(A)** were removed and the samples were saturated overnight in a basin of water, this was done by covering the blunt end of the ring with a piece of nylon cloth which was held in place by means of a rubber band, to disallow soil loss. A specially meshed container was used to hold the ring which was in turn, placed inside a plastic container. The container containing the sample was then inserted into the permeameter after establishing a constant head. A tube previously filled with water was used as a junction connecting the inside of the ring holder and the water in the permeameter. This ensured flow of water into a burette. The time **(T)** taken at which a conveniently chosen volume (**V**) is attainted in the burette is taken using a stop watch. The hydraulic height difference **(DH)** of water inside the ring holder and outside was measured and the permeability (hydraulic conductivity) **(K)** was calculated as follows;

$$K=\frac{V.L}{AT(DH)} \tag{6}$$

Where,

K = Permeability (cm/sec)

V = Volume of water collected (cm^3)

L = Length of sand column (cm)

A = Cross sectional area of the sample (equivalent to area of core ring) cm^2

T = Time (Sec).

DH = Hydraulic head difference (cm).

Sand sample were treated as cohesion less soil in the permeameter.

2.8 Filterability determination

Apparatus

- Hand glove, C456, Agary Limited, Malaysia
- Stop watch, HF Instrument, New York USA
- Brass Mesh
- Filter beds
- Graded and prepared sand from various sources.
- Water pump, 1.5 hp Peter's pump, Germany
- Pipes (PVC), Geepee Nigeria Ltd.
- Flow meter and Control valves, Gallenkamp Products, England
- Shovel, John.C, Size 14, England
- Rubber Gasket and hose (Flexible pipe of 20cm)
- Buckets (Plastic), 20 liters, OK plastic Nigeria Ltd.

- Thermometer, 110℃, Gallenkamp England

Reagents

- Raw Water
- Aluminium Sulphate

The filtration effectiveness of the sand as filter medium was determined using the filterability test.

(a) Preliminary treatment of raw water

In order to provide various level of initial turbidity for the filter operation and also to reduce the turbidity loading on the filters, preliminary experiments were carried out with jar-test apparatus to determine optimum alum dosage and optimum time for rapid and slow mix [8].

A 20 gram per litre stock solution of coagulant was prepared by dissolving 20 g of coagulant (aluminium sulphate Al_2 (SO_4). $18H_2O$ in a litre of distilled water. This solution was added to each of the 1000 ml raw water sample from river Benue by varying the quantities to give different coagulant doses of 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5 g/l [20]. The samples were stirred rapidly (rapid mix) for a period of 1 minute after which the stirring speed was reduced and stirring continued slowly for another 15 minutes. The coagulated water was allowed to settle for 27 minute [18]. Settle water samples were analysed for turbidity reduction and to obtain the optimum coagulant dose.

(b) Filtration experiment

- *Experimental Set-up*

In setting up the experimental set up as shown in Figure 3 inorder to investigate the filter beds (sands) used, these consist of a column 100 mm in diameter and 2.8 m in height. Sampling points were made across the lower end of the column for a distance of 120 cm at various intervals. Pipes were installed from the sampling point to the sampling containers. Reading of the effluent flow rate and effluent turbidity were measured at various time intervals.

- *Experimental Method*

Preparing the filter bed for the filter run involved filling the column with already graded and prepared sand. The depths of the filter beds inside the column were 120 cm.

Raw water from river Benue, which had be subjected to pre-treatment to attain required constant initial turbidity from the settle water tank was pumped into the overhead plastic bucket from which it was fed in to the filtration column via gravity. The rate of filling up the column was constantly maintained by a control valve and the inflow rate was maintained by flow meter. The primary variables investigated were; inflow rate, effluent flow rate, effluent turbidity as a function of time, bed depth and initial turbidity. The pressure drop across the filter beds was determined using modified Darcy - Wiesbach equations of head loss in pipe to reflect conditions in bed of porous media. The resulting equation, known as the Carmen-Kozeny modified equation [4]

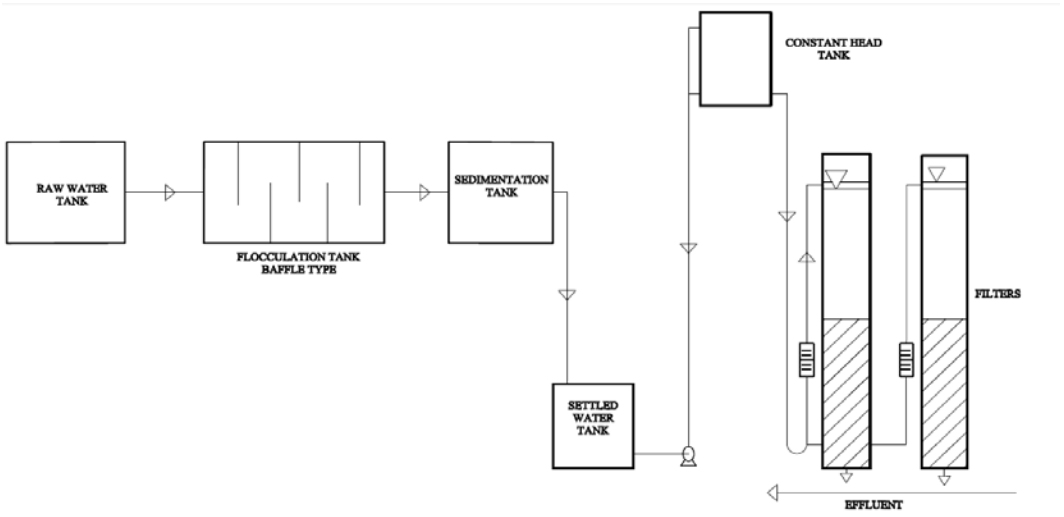

Figure 3: Schematic Diagram of Filtration Plant

$$h_f = \frac{f' L(1-e)V_s^2}{e^3 g d_p} \tag{7}$$

Where:

h_f = Friction loss through bed of particles of uniform size,

L = depth of the filter, m

e = porosity of bed

V_s = Filtering velocity, i.e the velocity of the water just above the bed

(total flow Q to the filter divided by the area of the filter), m/s

g= gravitational acceleration, m/s^2

d_p = Diameter of filter media grains

The remaining term f' is a friction factor related to the coefficient of drag around the particle. In the usual range of filter velocities (laminar flow) and can be calculated by

$$f' = 150\frac{(1-e)}{R_e} + 1.75 \tag{8}$$

Where:

$$\text{Reynolds number } (R_e) = \frac{\phi \rho_W V_S d}{\mu} \quad (8a)$$

And ρ_w and μ are the density and dynamic viscosity, respectively, of water. The units of ρ_w are kilograms per cubic meter (kg/m^3), and the units of μ are Newton-seconds per square meter ($N.s/m^2$). The shape factor ϕ ranges from 0.75 – 0.85 for most filter media [4].

Filtrate thus collected was monitored for turbidity until it deteriorated to unacceptable levels when this happened; the filters were taken out of operation and backwashed at a rate of 45.9 m/hr. This rate is near the lowest recommended backwash rate 37 m/hr according to [21]. Filter bed expansion at this rate was measured by recording the height of expanded filter bed and finding the increase in height as a percentage of bed expansion during backwashing.

(c) Turbidity Determination

The turbidity of the filtrates was obtained by standardizing the turbidity meter and reading the turbidity values of the water directly from the turbidity meter in accordance with manufacturer's instructions [22]. Turbidity was recorded in Nephelometric Turbidity Unit (NTU) [23].

3. Results

3.1 Particle Size Distribution

Details of particle size distribution of Rivers Benue Asa and Imported sand from Brazil are presented in Tables 2, 3 and 4 respectively. The Figures 4, 5 and 6 of the particle size distribution of the various river sands and the imported sand from Brazil are presented at Appendix A showing the Sands effective size D_{10} of 0.35 mm, 0.40 mm and 0.46 mm respectively, while the sieve allowing 60 % of the sample to pass through (D_{60}) was 0.50 mm, 0.55 mm, 0.50 mm and 0.68 mm respectively. The Uniformity Coefficients (U_c) which are the ratio of D_{60}/D_{10} are 1.43, 1.25 and 1.48 respectively.

Table 2: Particle Size Distribution of River Benue Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cumulative Mass Retained	% Passing
4.760	0	0	0	100
2.360	26.70	5.34	5.34	94.66
2.000	16.10	3.22	8.56	91.44
0.600	82.20	16.44	25.00	75.00
0.425	275.30	55.06	80.06	19.94
0.300	61.60	12.32	92.38	7.62
0.212	20.10	4.02	96.40	3.60
0.150	6.60	1.32	97.72	2.28
0.075	3.20	0.64	98.36	1.64

Table 3: Particle Size Distribution of River Asa Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cumulative Mass Retained	% Passing
4.760	0	0	0	100
2.360	18.20	3.64	3.64	96.36
2.000	14.00	2.80	6.44	93.56
0.600	90.70	18.14	24.58	75.42
0.425	308.90	61.78	86.36	13.64
0.300	37.90	7.58	93.94	6.06
0.212	17.00	3.40	97.34	2.66
0.150	5.10	1.02	98.36	1.64
0.075	1.30	0.26	98.62	1.38

Table 4: Particle Size Distribution of Imported Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cumulative Mass Retained	% Passing
4.760	0	0	0	100
2.360	12.10	2.42	2.42	97.58
2.000	14.80	2.96	5.38	94.62
0.600	142.20	28.44	33.82	66.18
0.425	305.10	61.02	94.84	5.16
0.300	18.30	3.66	98.50	1.50
0.212	3.50	0.70	99.20	0.80
0.150	2.40	0.48	99.68	0.32
0.075	0.30	0.06	99.74	0.26

3.1.1 Useful Portions as Filter Media

Table 5 shows the portions of stock sand that were too fine (P_F), Useable (P_U) and Coarse P_C as filter medium when graded to the values of uniformity coefficients and effective sizes as presented at appendix A. The table also shows corresponding portion's that would be obtained if sand samples were graded to recommended values of effective sizes of (0.50 mm) and uniformity coefficient (1.50).

River Benue sand had 48 % useable stock sand when graded to an effective size of 0.35 mm and uniformity coefficient of 1.43. The useable portion of this stock sand sample graded to the recommended effective size of 0.50 mm and uniformity coefficient of 1.5 was 56 %. Similarly, River Asa sand was 4 % when graded to an effective size of 0.40 mm and uniformity coefficient of 1.25, where the corresponding useable portion for the recommended values of effective size and uniformity coefficient is 52 %. The imported sand had 32 % useable stock sand when graded to an effective size of 0.46 mm and uniformity coefficient of 1.47 and when graded to the recommended values of effective size of 0.50 mm and uniformity coefficient of 1.50, it has a useable portion of 42 %. [24] also concluded that if sand from river Jewo will have 80 % of samples useable as filter media because of the rather higher of uniformity coefficient of 2.41.

Table 5: Fine, Useable and Coarse Portion of Stock Sand.

River Benue Sand.	Effective size (D_{10})	Uniformity Coefficient	fine portion (P_f) %	Useable Portion (P_U) %	Coarse Portion (P_C)%
Determined Values	0.35	1.43	12	48	76
Typical Values	0.50	1.50	18	56	84
River Asa Sand.					
Determined Values	0.40	1.25	9	4	72
Typical Values	0.50	1.50	20	52	84
Imported Sand					
Determined Values	0.46	1.47	8	32	78
Typical Values	0.50	1.50	10	42	81

3.2 Specific Gravity

The average specific gravity for each of the samples are presented in Table 6a - 6c shows the specific gravity of river sands from Benue, Asa and that of the imported sand with specific gravities of 2.67, 2.29 and 2.60 respectively. Sands from river Benue and the imported sand are within the recommended value **(> 2.50)** to be used as filter media because of the densities of all samples are higher than that of water.

Table 6a: Specific Gravity of River Benue Sand

Bottle No.		4	5	2	Average
Wt. of bottle + water (full)	(W4)	96.60	94.00	89.70	93.43
Wt. of bottle + Soil + water	(W3)	102.00	99.60	95.20	98.93
Wt. of bottle + Soil	(W2)	55.70	53.40	49.00	52.70
Wt. of bottle	(W1)	46.90	44.50	40.20	43.87
Wt. of Addition of Water	(W4 -W1)	49.70	49.50	49.50	49.56
Wt. of Water added to Soil	(W3 - W2)	46.30	46.20	46.20	46.23
Wt. of Soil	(W2 - W1)	8.80	8.90	8.80	8.88
Wt. of Water displaced by Soil	(W4 - W1) - (W3 - W2) = W	3.40	3.30	3.30	3.30
Specific Gravity of Soil Particle	(W2 - W1)/W				**2.67**

Table 6b: Specific Gravity of River Asa Sand

Bottle No.		2	4	5	Average
Wt. of bottle + water (full)	(W4)	89.70	96.50	94.40	93.53
Wt. of bottle + Soil + water	(W3)	95.10	103.00	101.10	99.73
Wt. of bottle + Soil	(W2)	48.90	57.40	58.60	54.97
Wt. of bottle	(W1)	40.20	47.00	44.70	43.97
Wt. of Addition of Water	(W4 -W1)	49.50	49.50	49.70	49.97
Wt. of Water added to Soil	(W3 - W2)	46.20	45.60	42.50	44.77
Wt. of Soil	(W2 - W1)	8.70	10.40	13.90	11.00
Wt. of Water displaced by Soil	(W4 - W1) - (W3 - W2) = W	3.30	3.90	7.20	4.80
Specific Gravity of Soil Particle	(W2 - W1)/W				**2.29**

Table 6c: Specific Gravity of Imported Sand

Bottle No.		2	4	5	Average
Wt. of bottle + water (full)	(W4)	93.25	93.70	88.50	91.82
Wt. of bottle + Soil + water	(W3)	98.60	99.25	93.90	97.25
Wt. of bottle + Soil	(W2)	52.35	53.00	47.70	51.02
Wt. of bottle	(W1)	43.55	44.15	38.85	42.19
Wt. of Addition of Water	(W4 -W1)	49.70	49.55	49.65	49.63
Wt. of Water added to Soil	(W3 - W2)	46.25	46.25	46.20	46.23
Wt. of Soil	(W2 - W1)	8.80	8.85	8.85	8.83
Wt. of Water displaced by Soil	(W4 - W1) - (W3 - W2) = W	3.45	3.30	3.45	3.40
Specific Gravity of Soil Particle	(W2 - W1)/W				**2.60**

3.3 Acid solubility

Table 7 presents the acid solubility of the two river sands and that of the imported sand from Brazil, the hydraulic acid solubility result shows that river Benue sand, Asa and Imported sand had acid solubility of 1.05 %, 2.10 % and 0.85 % respectively.

3.4 Other Physical Properties of the River Sands

Other physical properties of sand from rivers in Nigeria and imported sand are shown in Table 8. which indicates that sand from river Benue and the imported sand had a porosity of 42 % and 45 % respectively and is within the recommended range value of 35 % to 50 %, reported by [25] while that of river Asa had porosity of

51 % which is slightly out of the recommended range values

Table 7: Acid Solubility

River Benue Sand	Description	Weight (g)
	Initial Weight of Sand Sample	400
	Final Weight of Sand Sample	395.80
	Loss in Weight of Sand Sample	4.20
	% Solubility	**1.05**
River Asa Sand		
	Initial Weight of Sand Sample	400
	Final Weight of Sand Sample	391.60
	Loss in Weight of Sand Sample	8.40
	% Solubility	**2.10**
Imported Sand		
	Initial Weight of Sand Sample	400
	Final Weight of Sand Sample	396.6
	Loss in Weight of Sand Sample	3.4
	% Solubility	**0.85**

Table 8: Other Physical Properties

River Sands	Porosity (%)	Permeability(cm/sec)
River Benue	42	0.47
River Asa	51	1.06
Imported Sand	45	0.35

3.5 Filtration Effectiveness

3.5.1 Pre-treatment Result

A number of chemicals have been employed for a long time in various dosages as coagulation agents [26] as a means of pre-treatment. Jar Test experiment was carried out in order to reduce the amount of turbidity on the filter beds and the results is presented in Table 9a plotted in Figure 7a at Appendix B, also showing the jar test result in Table 9b and plotted Figure 7b for the imported sand from Brazil at Appendix B. The result reveals that, alum dose of 0.75 g/l has the highest effect on turbidity removal.

Table 9a: Jar Test Result for Local Sands

Raw water Turbidity = **425 NTU**
Raw Water pH = **6.9**
Raw Water Alkalinity = **32 mg/l**

Jar No.	Alum Dose (mg/L)	Settle Water Characteristics				
		Appearance	**pH**	**Turbidity (NTU)**	**T. Removal (NTU)**	**% T. Removal**
0	-	Dirty	6.9	405	20	4.71
1	0.25	Very Cloudy	6.5	290	135	31.76
2	0.5	Cloudy	5.4	116	309	72.71
3	**0.75**	Slightly Cloudy	4.7	**32**	393	**92.47**
4	1	Slightly Cloudy	4.2	57	368	86.59
5	1.25	Cloudy	3.5	118	307	72.24
6	1.5	Cloudy	3.1	182	243	57.18

Table 9b: Jar Test Result For Imported Sand

Raw water Turbidity = **485 NTU**
Raw Water pH = **6.9**
Raw Water Alkalinity = **38 mg/l**

Jar No.	Alum Dose (mg/L)	Settle Water Characteristics				
		Appearance	**pH**	**Turbidity (NTU)**	**T. Removal (NTU)**	**% T. Removal**
0	-	Dirty	6.7	462	23	4.74
1	0.25	Very Cloudy	6.3	280	205	42.27
2	0.5	Cloudy	5.7	132	353	72.78
3	**0.75**	Slightly Cloudy	4.8	**38**	**447**	**92.16**
4	1	Slightly Cloudy	4.5	49	436	89.9
5	1.25	Cloudy	3.6	126	359	74.02
6	1.5	Cloudy	3.2	192	293	60.41

3.5.2 Filtration Tests

The filtration test results are presented in Tables 10 – 15.

3.5.3 Filtrate Quality

The filtrate quality results are presented in Table 16 – 21.

Table 10: Head Loss Development through media with time for River Benue Sand
(Filtration Rate = 6.45 m/hr)

Depth(cm) /Time(hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.014	0.073	0.162	0.250	0.338	0.427	0.515	0.603	0.692
2	0	0.440	0.162	0.338	0.515	0.692	0.869	1.045	1.222	1.399
3	0	0.073	0.250	0.515	0.780	1.045	1.310	1.575	1.840	2.105
4	0	0.103	0.338	0.692	1.045	1.399	1.752	2.105	2.459	2.812
5	0	0.132	0.427	0.869	1.310	1.752	2.194	2.636	3.077	3.519
6	0	0.162	0.515	1.045	1.575	2.105	2.636	3.166	3.696	4.226
7	0	0.191	0.603	1.222	1.840	2.459	3.077	3.696	4.314	4.933
8	0	0.221	0.692	1.399	2.105	2.812	3.519	4.226	4.933	5.639
9	0	0.250	0.780	1.575	2.370	3.166	3.961	4.756	5.551	6.346
10	0	0.280	0.869	1.752	2.636	3.519	4.403	5.286	6.170	7.053
11	0	0.309	0.912	1.929	2.901	3.872	4.844	5.816	6.788	7.760
12	0	0.338	1.045	2.105	3.166	4.226	5.286	6.346	7.406	8.467
13	0	0.368	1.134	2.282	3.431	4.579	5.728	6.876	8.025	9.173
14	0	0.397	1.222	2.459	3.696	4.933	6.170	7.406	8.643	9.880
15	0	0.427	1.310	2.636	3.961	5.286	6.611	7.937	9.262	10.587
16	0	0.456	1.399	2.812	4.226	5.639	7.053	8.467	9.880	11.294

Table 11: Head Loss Development through media with time for River Benue Sand
(Filtration Rate = 9.65 m/hr)

Depth(cm)/ Time(hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.031	0.124	0.264	0.403	0.542	0.682	0.821	0.960	1.099
2	0	0.078	0.264	0.542	0.821	1.099	1.378	1.657	1.935	2.214
3	0	0.124	0.403	0.821	1.239	1.657	2.075	2.492	2.910	3.328
4	0	0.171	0.542	1.099	1.657	2.214	2.771	3.328	3.886	4.443
5	0	0.217	0.682	1.378	2.075	2.771	3.468	4.164	4.861	5.557
6	0	0.264	0.821	1.657	2.492	3.328	4.164	5.000	5.836	6.687
7	0	0.310	0.960	1.935	2.910	3.886	4.861	5.836	6.811	7.786
8	0	0.356	1.099	2.214	3.328	4.443	5.557	6.672	7.786	8.901
9	0	0.403	1.239	2.492	3.746	5.000	6.254	7.507	8.761	10.015
10	0	0.449	1.378	2.771	4.164	5.557	6.950	8.343	9.736	11.129
11	0	0.496	1.517	3.050	4.582	6.114	7.647	9.179	10.711	12.244
12	0	0.542	1.657	3.328	5.000	6.672	8.343	10.015	11.687	13.358
13	0	0.589	1.796	3.607	5.418	7.229	9.040	10.851	12.662	**14.467**

Table 12: Head loss development through media with time for river asa sand

(Filtration rate= 6.45 m/hr)

Depth(cm)/ Time(hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.216	0.314	0.461	0.609	0.756	0.903	1.050	1.198	1.345
2	0	0.265	0.461	0.756	1.05	1.345	1.639	1.934	2.228	2.523
3	0	0.314	0.609	1.05	1.492	1.934	2.376	2.817	3.259	3.701
4	0	0.363	0.756	1.345	1.934	2.523	3.112	3.701	4.290	4.879
5	0	0.412	0.903	1.639	2.376	3.112	3.848	4.584	5.32	6.057
6	0	0.461	1.050	1.934	2.817	3.701	4.584	5.468	6.351	7.235
7	0	0.511	1.198	2.228	3.259	4.290	5.320	6.351	7.382	8.413
8	0	0.560	1.345	2.523	3.701	4.879	6.057	7.235	8.413	9.590
9	0	0.609	1.492	2.817	4.143	5.468	6.793	8.118	9.443	10.768
10	0	0.658	1.639	3.112	4.584	6.057	7.529	9.001	10.474	11.946
11	0	0.707	1.787	3.406	5.026	6.646	8.265	9.885	11.505	13.124
12	0	0.756	1.934	3.701	5.468	7.235	9.001	10.768	12.535	14.302
13	0	0.805	2.081	3.995	5.909	7.824	9.738	11.652	13.566	15.481
14	0	0.854	2.228	4.290	6.351	8.413	10.474	12.535	14.597	16.658
15	0	0.903	2.376	4.584	6.793	9.001	11.21	13.419	15.627	17.836
16	0	0.952	2.523	4.879	7.235	9.59	11.946	14.302	16.658	**19.014**

Table 13: Head loss development through media with time for river asa sand.

(Filtration rate= 9.65 m/hr)

Depth(cm)/ Time(hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.245	0.400	0.632	0.865	1.097	1.330	1.562	1.795	2.027
2	0	0.322	0.632	1.097	1.562	2.027	2.492	2.957	3.422	3.887
3	0	0.400	0.865	1.562	2.260	2.957	3.655	4.352	5.050	5.747
4	0	0.477	1.097	2.027	2.957	3.887	4.817	5.747	6.677	7.607
5	0	0.555	1.330	2.492	3.655	4.817	5.980	6.677	8.305	9.467
6	0	0.632	1.562	2.957	4.352	5.747	7.142	8.537	9.932	11.327
7	0	0.710	1.795	3.422	5.050	6.677	8.305	9.932	11.560	13.187
8	0	0.802	2.027	3.887	5.747	7.607	9.467	11.327	13.187	15.047
9	0	0.865	2.260	4.352	6.445	8.537	10.630	12.722	14.815	16.907
10	0	0.942	2.492	4.817	7.142	9.467	11.792	14.117	16.442	18.767
11	0	1.020	2.747	5.282	7.840	10.397	12.955	15.512	18.070	20.627
12	0	1.097	2.957	5.747	8.537	11.327	14.117	16.907	19.697	22.487
13	0	1.175	3.190	6.212	9.235	12.257	15.280	18.302	21.325	**24.347**

Table 14: Head loss development through media with time for imported sand

(Filtration rate = 6.45 m/hr)

Depth(cm) /Time (hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.001	0.06	0.149	0.237	0.325	0.414	0.502	0.59	0.679
2	0	0.427	0.149	0.325	0.502	0.679	0.856	1.032	1.209	1.386
3	0	0.06	0.237	0.502	0.767	1.032	1.297	1.562	1.827	2.092
4	0	0.09	0.325	0.679	1.032	1.386	1.739	2.092	2.446	2.799
5	0	0.119	0.414	0.856	1.297	1.739	2.181	2.623	3.064	3.506
6	0	0.149	0.502	1.032	1.562	2.092	2.623	3.153	3.683	4.213
7	0	0.178	0.59	1.209	1.827	2.446	3.064	3.683	4.301	4.920
8	0	0.208	0.679	1.386	2.092	2.799	3.506	4.213	4.92	5.626
9	0	0.237	0.767	1.562	2.357	3.153	3.948	4.743	5.538	6.333
10	0	0.267	0.856	1.739	2.623	3.506	4.390	5.273	6.157	7.040
11	0	0.296	0.899	1.916	2.888	3.859	4.831	5.803	6.775	7.747
12	0	0.325	1.032	2.092	3.153	4.213	5.273	6.333	7.393	8.454
13	0	0.355	1.121	2.269	3.418	4.566	5.715	6.863	8.012	9.160
14	0	0.384	1.209	2.446	3.683	4.920	6.157	7.393	8.63	9.867
15	0	0.414	1.297	2.623	3.948	5.273	6.598	7.924	9.249	10.574
16	0	0.443	1.386	2.799	4.213	5.626	7.04	8.454	9.867	**11.281**

Table 15: Head loss development through media with time for imported sand

(Filtration rate = 9.65 m/hr)

Depth(cm) /Time(hr)	0	5	15	30	45	60	75	90	105	120
1	0	0.018	0.111	0.251	0.390	0.529	0.669	0.808	0.947	1.086
2	0	0.065	0.251	0.529	0.808	1.086	1.365	1.644	1.922	2.201
3	0	0.111	0.390	0.808	1.226	1.644	2.062	2.479	2.897	3.315
4	0	0.158	0.529	1.086	1.644	2.201	2.758	3.315	3.873	4.430
5	0	0.204	0.669	1.365	2.062	2.758	3.455	4.151	4.848	5.544
6	0	0.251	0.808	1.644	2.479	3.315	4.151	4.987	5.823	6.674
7	0	0.297	0.947	1.922	2.897	3.873	4.848	5.823	6.798	7.773
8	0	0.343	1.086	2.201	3.315	4.430	5.544	6.659	7.773	8.888
9	0	0.39	1.226	2.479	3.733	4.987	6.241	7.494	8.748	10.002
10	0	0.436	1.365	2.758	4.151	5.544	6.937	8.330	9.723	11.116
11	0	0.483	1.504	3.037	4.569	6.101	7.634	9.166	10.698	12.231
12	0	0.529	1.644	3.315	4.987	6.659	8.330	10.002	11.674	13.345
13	0	0.576	1.783	3.594	5.405	7.216	9.027	10.838	12.649	**14.454**

Table 16: Filtrate turbidity changes through media with time for river benue sand.
(Filtration Rate = 6.45 m/hr, Inflow Turbidity = 32 NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	20.42	15.79	11.92	8.95	6.82	5.20	3.81	2.87	2.04
2	19.66	15.20	11.4	8.56	6.46	4.84	3.66	2.75	2.00
3	19.03	14.72	11.05	8.28	6.19	4.68	3.54	2.63	1.98
4	18.42	14.29	10.73	8.04	6.03	4.57	3.42	2.56	1.96
5	17.85	13.85	10.42	7.81	5.87	4.41	3.30	2.51	1.92
6	17.25	13.42	10.10	7.57	5.67	4.29	3.22	2.43	1.90
7	16.54	12.71	9.63	7.29	5.40	4.05	3.06	2.31	1.88
8	15.99	12.31	9.23	6.94	5.20	3.93	2.95	2.23	1.84
9	15.28	11.68	8.80	6.70	4.96	3.74	2.79	2.12	1.80
10	14.64	11.44	8.60	6.46	4.84	3.62	2.75	2.04	1.76
11	14.56	11.48	8.56	6.41	4.76	3.31	2.66	1.96	1.74
12	14.51	11.46	8.51	6.36	4.71	3.26	2.61	1.86	1.72
13	14.46	11.44	8.46	6.31	4.66	3.21	2.54	1.87	1.71
14	14.95	11.97	9.04	6.74	5.08	3.80	2.83	2.10	1.85
15	15.42	12.29	9.24	6.88	5.20	3.92	2.92	2.20	1.92
16	15.91	12.50	9.47	7.04	5.28	3.96	2.99	2.26	**2.01**

Table 17: Filtrate Turbidity changes through media with time for River Benue Sand.
(Filtration rate = 9.65 m/hr, Inflow turbidity = 32 NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	20.85	16.38	12.51	9.55	7.41	5.79	4.41	3.64	2.59
2	19.86	15.79	12.00	9.15	7.06	5.51	4.25	3.34	2.51
3	19.39	15.16	11.64	8.87	6.78	5.28	4.13	3.22	2.47
4	18.56	14.88	11.32	8.64	6.46	5.16	4.01	3.14	2.39
5	18.08	14.45	10.97	8.36	6.31	4.96	3.85	3.06	2.31
6	17.41	13.93	10.53	8.16	6.19	4.88	3.74	2.91	2.23
7	16.78	13.26	10.06	7.81	5.99	4.64	3.62	2.79	2.19
8	16.19	12.75	9.70	7.53	5.75	4.49	3.54	2.71	2.15
9	16.61	13.21	9.93	7.59	5.75	4.54	3.56	2.80	2.32
10	17.06	13.7	10.29	7.79	5.87	4.58	3.63	2.92	2.44
11	17.32	13.77	10.32	7.95	6.27	4.90	3.90	3.11	2.59
12	17.78	14.12	10.78	8.04	6.37	5.06	3.95	3.17	2.62
13	17.86	14.47	10.63	8.18	6.41	5.18	4.00	3.25	**2.79**

Table 18: Filtrate turbidity changes through media with time for river asa sand
(Filtration rate = 6.45 m/hr, Inflow turbidity = 32NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	23.5	18.87	15.00	12.03	9.90	8.28	6.89	5.95	5.12
2	22.74	18.28	14.48	11.64	9.54	7.92	6.74	5.83	5.08
3	22.11	17.80	14.13	11.36	9.27	7.76	6.62	5.71	5.06
4	21.50	17.37	13.81	11.12	9.11	7.65	6.50	5.64	5.04
5	20.93	16.93	13.50	10.89	8.95	7.49	6.38	5.59	5.00
6	20.33	16.50	13.18	10.65	8.75	7.37	6.30	5.51	4.98
7	19.62	15.79	12.71	10.37	8.48	7.13	6.14	5.39	4.96
8	19.07	15.39	12.31	10.02	8.28	7.01	6.03	5.31	4.92
9	18.36	14.76	11.88	9.78	8.04	6.82	5.87	5.20	4.88
10	17.72	14.52	11.68	9.54	7.92	6.70	5.83	5.12	4.84
11	17.64	14.56	11.64	9.49	7.84	6.39	5.74	5.04	4.82
12	17.59	14.54	11.59	9.44	7.79	6.34	5.69	4.94	4.80
13	17.54	14.52	11.54	9.39	7.74	6.29	5.62	4.95	4.79
14	18.03	15.05	12.12	9.82	8.16	6.88	5.91	5.18	4.93
15	18.50	15.37	12.32	9.96	8.28	7.00	6.00	5.28	5.00
16	18.99	15.58	12.55	10.12	8.36	7.04	6.07	5.34	**5.09**

Table 19: Filtrate turbidity changes through media with time for river asa sand.
(Filtration rate = 9.65 m/hr; Inflow turbidity = 32 NTU)

Depth (cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	23.93	19.46	15.59	12.63	10.49	8.87	7.49	6.72	5.67
2	22.94	18.87	15.08	12.23	10.14	8.59	7.33	6.42	5.59
3	22.47	18.24	14.72	11.95	9.86	8.36	7.21	6.30	5.55
4	21.64	17.96	14.40	11.72	9.54	8.24	7.09	6.22	5.47
5	21.16	17.53	14.05	11.44	9.39	8.04	6.93	6.14	5.39
6	20.49	17.01	13.61	11.24	9.27	7.96	6.82	5.99	5.31
7	19.86	16.34	13.14	10.89	9.07	7.72	6.70	5.87	5.27
8	19.27	15.83	12.78	10.61	8.83	7.57	6.62	5.79	5.23
9	19.69	16.29	13.01	10.67	8.83	7.62	6.64	5.88	5.40
10	20.14	16.78	13.37	10.87	8.95	7.66	6.71	6.00	5.52
11	20.40	16.85	13.40	11.03	9.35	7.98	6.98	6.19	5.67
12	20.86	17.20	13.86	11.12	9.45	8.14	7.03	6.25	5.70
13	20.94	17.55	13.71	11.26	9.49	8.26	7.08	6.33	**5.87**

Table 20: Filtrate Turbidity Changes through media with time for Imported Sand

(Filtration rate = 6.45 m/hr; Inflow turbidity = 38 NTU)

Depth(cm) /Time(hr)	5	15	30	45	60	75	90	105	120
1	19.54	14.91	11.04	8.07	5.94	4.32	2.93	1.99	1.16
2	18.78	14.32	10.52	7.68	5.58	3.96	2.78	1.87	1.12
3	18.15	13.84	10.17	7.40	5.31	3.80	2.66	1.75	1.10
4	17.54	13.41	9.85	7.16	5.15	3.69	2.54	1.68	1.08
5	16.97	12.97	9.54	6.93	4.99	3.53	2.42	1.63	1.04
6	16.37	12.54	9.22	6.69	4.79	3.41	2.34	1.55	1.02
7	15.66	11.83	8.75	6.41	4.52	3.17	2.18	1.43	1.00
8	15.11	11.43	8.35	6.06	4.32	3.05	2.07	1.35	0.96
9	14.40	10.80	7.92	5.82	4.08	2.86	1.91	1.24	0.92
10	13.76	10.56	7.72	5.58	3.96	2.74	1.87	1.16	0.88
11	13.68	10.60	7.68	5.53	3.88	2.43	1.78	1.08	0.86
12	13.63	10.58	7.63	5.48	3.83	2.38	1.73	0.98	0.84
13	13.58	10.56	7.58	5.43	3.78	2.33	1.66	0.99	0.83
14	14.07	11.09	8.16	5.86	4.20	2.92	1.95	1.22	0.97
15	14.54	11.41	8.36	6.00	4.32	3.04	2.04	1.32	1.04
16	15.03	11.62	8.59	6.16	4.40	3.08	2.11	1.38	**1.13**

Table 21: Filtrate Turbidity changes through media with time for Imported Sand

(Filtration rate = 9.65 m/hr; Inflow turbidity = 38 NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	20.18	15.71	11.84	8.88	6.74	5.12	3.74	2.97	1.92
2	19.19	15.12	11.33	8.48	6.39	4.84	3.58	2.67	1.84
3	18.72	14.49	10.97	8.20	6.11	4.61	3.46	2.55	1.80
4	17.89	14.21	10.65	7.97	5.79	4.49	3.34	2.47	1.72
5	17.41	13.78	10.3	7.69	5.64	4.29	3.18	2.39	1.64
6	16.74	13.26	9.86	7.49	5.52	4.21	3.07	2.24	1.56
7	16.11	12.59	9.39	7.14	5.32	3.97	2.95	2.12	1.52
8	15.52	12.08	9.03	6.86	5.08	3.82	2.87	2.04	1.48
9	15.94	12.54	9.26	6.92	5.08	3.87	2.89	2.13	1.65
10	16.39	13.03	9.62	7.12	5.20	3.91	2.96	2.25	1.77
11	16.65	13.10	9.65	7.28	5.60	4.23	3.23	2.44	1.92
12	17.11	13.45	10.11	7.37	5.70	4.39	3.28	2.50	1.95
13	17.19	13.8	9.96	7.51	5.74	4.51	3.33	2.58	**2.12**

3.5.4 Backwash Results

The backwash results are presented in Table 22 – 24 all at backwash rate of 45.9 m/hr and these plotted at (Appendix E); Figure 8 – 10

Table 22: River benue sand, (Bed expansion = 25.8 %)

Backwash Time (min)	0.5	1	1.5	2	3	4	5	6	7	8	10	12	15
Waste Turbidity (NTU)	15	34	375	230	64	36	21	20	18	17	17	17	17

Table 23: River asa sand (Bed expansion = 56.6 %)

Backwash Time (min)	0.5	1	1.5	2	3	4	5	6	7	8	10	12	15
Waste Turbidity(NTU)	22	36	409	216	72	32	25	21	20	19	18	18	18

Table 24: Imported sand (Bed expansion = 22.2 %)

Backwash Time (min)	0.5	1	1.5	2	3	4	5	6	7	8	10	12	15
Waste Turbidity(NTU)	12	28	365	210	54	33	18	19	16	15	14	14	14

4. Discussions

4.1 Sand Media Properties

4.1.1 Particle Size Distribution

The effective size and uniformity coefficient of river Benue and that of the imported sand are quite close indicating that their grain size range is almost similar as shown in Table F (Appendix F), which is within the recommended values for filter media [27,18]. This suggests their performance in water treatment might pr oduce close results. [27,18,24] recommended that effective sizes of value greater than 0.75 mm and uniformity coefficient of 1.6 is to be used for river jewo sand in orire local government area of oyo state. River Asa sand was out of the recommended range values which might be due to the particle sizes of the sand and it chemical composition of 2.10% of acid solubility and also [28] also recommended range of 0.35 – 1.00 for effective sizes and uniformity coefficient of 1.2 – 1.8 for Yola and shelleng sand to be used as filter media. [12] Suggested uniformity co-efficient of 1.9 which is differ from the universal Uniformity Co-efficient of 1.3 – 1.8.

4.1.2 Acid Solubility

The low acid solubility results from the acid solubility test carried out indicate that, the level of hydrogen carbonate or calcium carbonate of river sands from Benue and the imported sand have values within the recommended range value of acid solubility while that of river Asa was slightly out of the range value of acid solubility of 1 – 2 % (WHO, 2004) as show in Table 4.6. This indicate that; imported sand from Brazil and river Benue sands have a low hydrogen carbonate content of 0.85 % and 1.05 % respectively while sands from river Asa have a higher content of hydrogen carbonate with 2.10 % which might not give a good filtration when used as a filter media.

4.1.3 Specific Gravity

The specific gravity of individual filter grains is one of several factors important in determining the rate of water flow to achieve a certain bed expansion during backwashing at a given water temperature. It is also one of several factors that determine the rate at which media grains settle after backwashing. In systems where combined air scour and water washing takes place over a weir it determines the size of stilling zone adjacent to the weir necessary to reduce media losses [11].

The average specific gravity for each of the samples is presented in Tables 6a – 6c. The specific gravity of sands from river Benue and the imported sand from Brazil have specific gravity of 2.67 and 2.60 respectively which are higher than that of water and are within the recommended value greater than 2.50. The specific gravity parameter is an indication that during backwashing of the filter media, river Asa sand with 2.29 specific gravity will require less critical fluidization velocity or force for bed expansion. It becomes more difficult to separate the particulate, since it is collected over water during this process. However, the low densities of river Asa suggested that, it cannot be used as filter material.

4.1.4 Other Physical Properties

The physical properties of sands from river Benue and imported sand falls within the recommended value for sand filter as shown in Table 8. The result presented in Table 8 indicates that river Asa sand might not be too good as a filter media due to the values of the porosity, permeability and Uniformity Coefficient that are out of the recommended values as shown in Appendix F; Table F. Asa river sand may lead to higher clogging effect due to irregular shape. This shows that river Asa sand might developed head loss faster at different hydraulic loading than sands from river Benue and imported sand. This is in accordance to [29] that head loss is very dependent on porosity, and reduction in porosity leads to increase in head loss.

The porosity and permeability parameters are very important in the choice of a suitable filtering material. This is because if permeability is too high, no meaningful filtration can take place and if too low, the bed gets easily clogged and it becomes uneconomical to operate since it will require frequent backwashing.

4.2 Filtration Effectiveness

(a) Jar Test

The jar test results presented in Table 9a and Table 9b revealed that, alum dose of 0.75mg/l has the highest effect on turbidity value of 32 NTU and 38 NTU respectively Hence, this dose was chosen as the optimum required for turbidity removal.

From the result it can be seen that at low alum dose (less than 0.5 mg/l) the alum added was insufficient and hence result in destabilization of the turbidity species, probably because insufficient charges of the appropriate nature have been added and adsorbed to produce neutralization. A region of optimum dosage was however observed at a dosage of 0.75 mg/l. suggesting that effective charge neutralization has occurred.

4.2.1 Head Loss Development

Filtration rate (hydraulic loading) can influence the performance of a filter bed due to several factors. An increase in volume of flow per unit time gives an increase in weight of the material deposited in the filter pores. The use of higher flow rate produces a greater pressure drop across the clean filters and a greater drop per unit of material deposited, if this is evenly distributed through the filter bed. The change in velocity within the filter bed can alter the removal of the particles and the distribution of deposits in the bed, and hence influence the removal capacity and efficiency.

4.2.2 *Filter Run Time*

The filter run times can be measured either through the attainment of maximum design head loss or by the deterioration of the quality to an unacceptable level as stated by [29].

For the high filtration rates used and for the turbidity loading used, the result obtained for the filter run time are quite significant and very encouraging. 16 hours of operation at a filtration rate of 6.45 m/hr for the three river sands and imported sand with an inflow turbidity loading of 32 NTU and 38 NTU respectively. The effluent turbidity were 2.01 NTU, 5.09 NTU and 1.13 NTU for river Benue, Asa and imported sand respectively as shown in Tables 16, 18 and 20 while at 13 hour of operation at a higher rate of 9.65 m/hr, the effluent turbidity were 2.79 NTU, 5.87 NTU and 2.12 NTU respectively as shown in Tables 17, 19 and 21. These values of sands from river Benue and imported sand from Brazil are well below the WHO maximum permissible level of 5.00 NTU while that of river Asa sand at a low filtration rate of 6.45 m/hr and at higher filtration rate of 9.65 m/hr. had a effluent turbidity of 5.09 NTU and 5.87 NTU respectively, which are slightly above the WHO standard for drinking water which cannot be used as a filter media. Filter run times should not be more less than 12 hours and more than 24 hours was recommended by [30] to reduce labour needed to run the plant, also [12] recommended 16 hours at rates of 6.25 m/hr and 22 hours for turbidity load of 10 NTU.

It can be observed that an increase in the hydraulic loading rate resulted to reduction of filter running time. This shows that the hydraulic loading rate is inversely proportional to filter running time.

4.2.3 Filtration quality

It is assumed that cleaner filter media would result in an improved quality of filtrate. Filtrate quality was monitored to establish the effective cleaning.

The river sands and imported sand media from Brazil reduced the turbidity level of settled water from 32 NTU and 38 NTU to 2.01 NTU, 5.09 NTU and 1.13 NTU respectively at filtration rate of 6.45 m/hr at depth of 120 cm for 16 hrs of operation (Tables 16, 18 and 20) With percentage turbidity removal of 93.72 %, 84.09 % and 97.03 % as shown in Appendix I, (Tables I1, I5 and I7) for river Benue, Asa and imported sand from Brazil respectively. Also at higher filtration rate of 9.45 m/hr, the level turbidity of settled water from 32 NTU and 38 NTU to 2.79 NTU, 5.87 NTU and 2.12 NTU at depth of 120 cm for 13 hrs of operation (Tables 17, 19 and 21), with percentage of turbidity removal of 91.28 %, 81.66 % and 94.42 % (Tables I2, I6 and I8) for sands from river Benue, Asa and imported sand from Brazil respectively (Appendix I).

It can be observed that an increase in hydraulic loading resulted to reduction of filtrate quality. Increase in hydraulic loading increased the rate at which materials were deposited on the filter bed. An increase in filter depth also improved the filtration performance in terms of filtrate quality and output. This suggests that absorption occurs through the filter column in purifying the water.

4.2.4 Backwashing

As already mentioned in section 4.2.2 (Filter run times), maximum head loss attainment determined the termination of filter runs and therefore the commencement of filter cleaning (backwashing).

Table 4.26 – 4.28 show that a backwash rate of 45.9 m/hr was adequate for all sands. However, while the river Benue and Asa sand produced expansions of 25.8 % and 56.6 % respectively, the imported sand from Brazil produced a slightly lower expansion of 22.2 % at this backwash rate. At 10 minutes river Benue, Asa sands and imported sand from Brazil has waste turbidity of 17 NTU, 18 NTU and 14 NTU respectively after backwashing at a backwash rate of 45.9 m/hr which indicates that all the impurities could not be washed out through backwashing alone.

Although these expansion values border on the lower limits of recommended expansion of between 20 - 50 % [21], he also found a back was rate of 37.5 to 50 m/hr are adequate for satisfactory cleaning. [31] suggested an optimum back wash rate of 41.75 m/hr with a small expansion of 16 – 18 % and back wash duration of 6 -12 minutes. While [12] using local sand (Kaduna river) recommended 40 m/hr and duration of 10 minute to reduce quantity of clear water usage. [28] recommended 42.9 m/hr and expansion of 20 – 50 %. It is believed that a slightly higher rate of backwashing will expand the bed sufficiently to enable better washing. A better washing of the filter media could be achieved by providing for surface wash or through air scour prior to backwash.

5. Conclusion and Recommendations

The following conclusions were derived from the experimental study

- In this study, Low filtration rate of 6.45 m/hr gave effective turbidity removal and higher percentage turbidity removal.
- A filter depth of 120 cm was found to be adequate for the filtration process.
- River sands were assessed, evaluated and it was found that river Benue sand have full potential for usage in filtration as that of imported sand (filter media) in water treatment plants than that of river Asa sand.

- Sand filter media prepared satisfied specifications relating to physical properties such as appearance/cleanliness, size grading, Specific gravity, Acid solubility, porosity and permeability of filter sands.
- If properly graded to recommended standards of effective size and uniformity coefficient, the sands analysis would perform better.
- The porosity, permeability, specific gravity, Acid solubility and filterability of River Benue sand followed the same trend with that of the imported sand from Brazil and it was found to have direct relationship with media sizes (particle size) and density, as established by other investigators.
- River Asa sand cannot be used as filter media because of most of its physical properties are not of the recommended values which did not give good percent result of Turbidity removal.
- Filter washing time of ten (10) minutes was found to be adequate at the backwash rate of 45.9 m/hr without surface wash or air scour and produced an expansion of filter bed within recommended limits of 20 – 50 %.

In view of the findings and observations in this study and for further research, the following suggestions and recommendations are made:

- An effective size of 0.45 mm and uniformity coefficient of 1.8 is recommended for these river sands. This will ensure the use of over 65 % of the stock samples as filter media. It is therefore recommended that, studies should also be made on the sand size with Uniformity coefficient ($\boldsymbol{U_c}$) of 1.2 – 1.8

- Nigeria should stop the importation of imported sand and make use of our local sand as filter media since it have similar properties as filter media and it will reduce cost.
- Adequate pre-treatment of raw water to improve filterability is desirable in the satisfactory performance of filters. Most filter problems arise from the neglect of this necessary and important factor. It is therefore recommended that water supply agencies should equip themselves to meet the demand of this indispensable factor in the filtration process.

- Surface wash or air scour prior to backwash when using these sands, is recommended. This will greatly improve the washing of the sand media at the backwash rate of 45.9 m/hr with filter bed expansion of between 20 – 50 %. Alternatively, the backwash rate could be raised slightly to increase fluidization of the bed, so that particles have a greater chance of rubbing against one another to increase motion.

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Appendix A

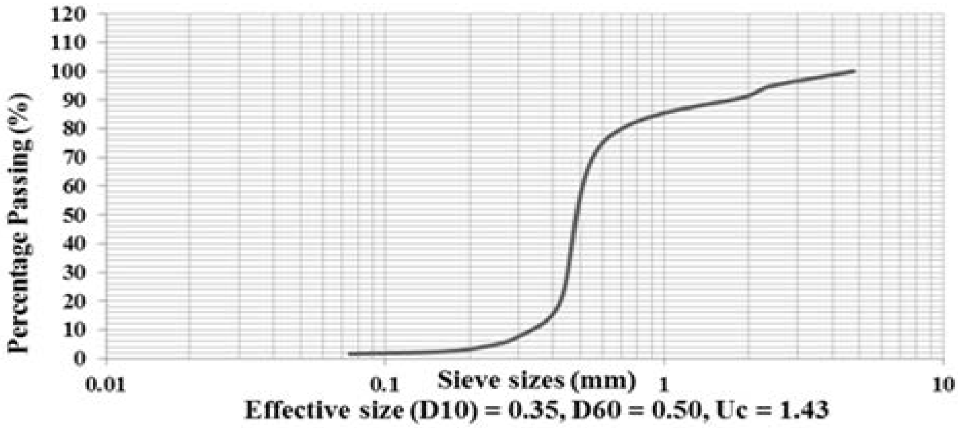

Figure 4: Particle size distribution of river benue sand.

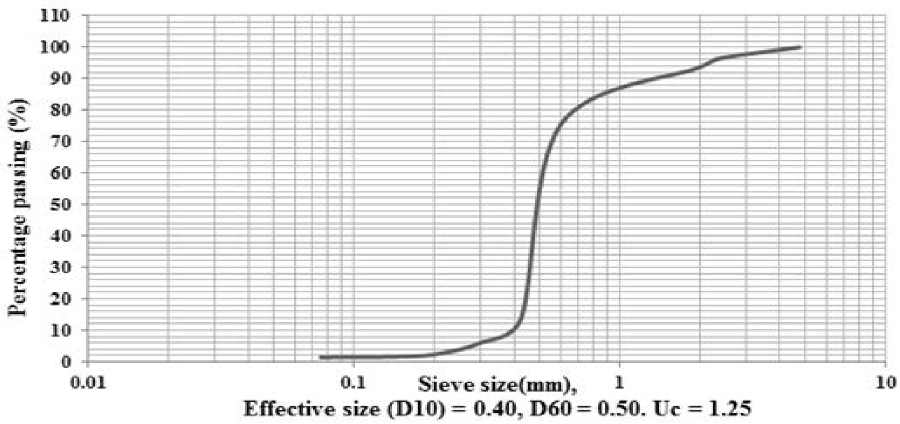

Figure 5: Particle size distribution of river asa sand

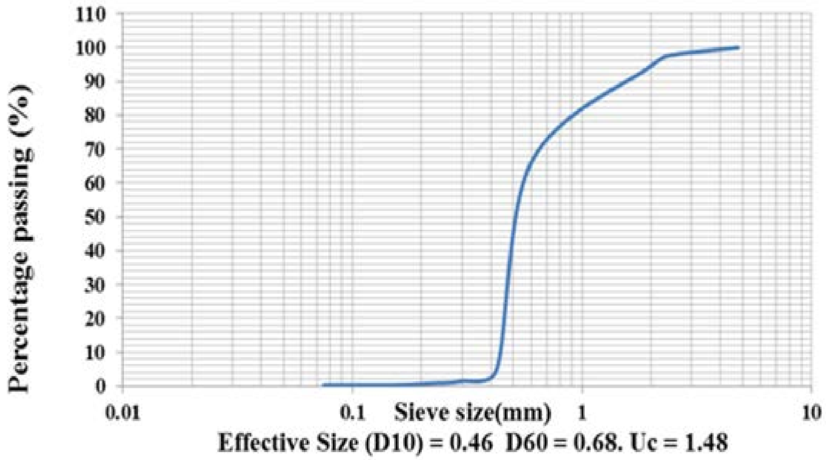

Figure 6: Particle Size Distribution of Imported Sand.

Appendix B

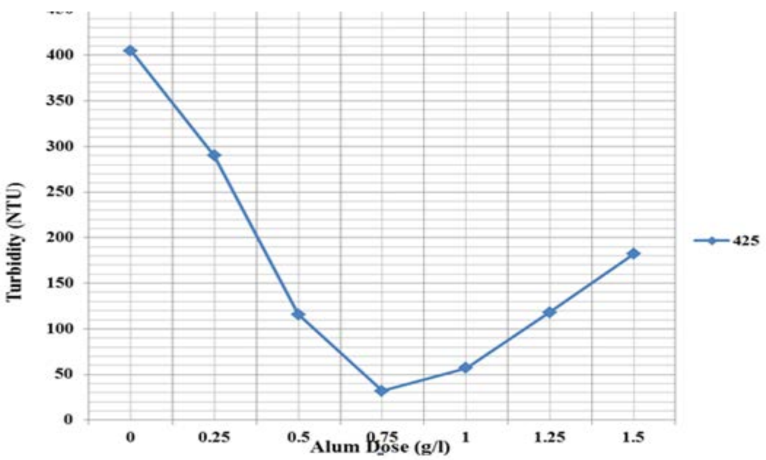

Figure 7a: Jar test results for local sands.

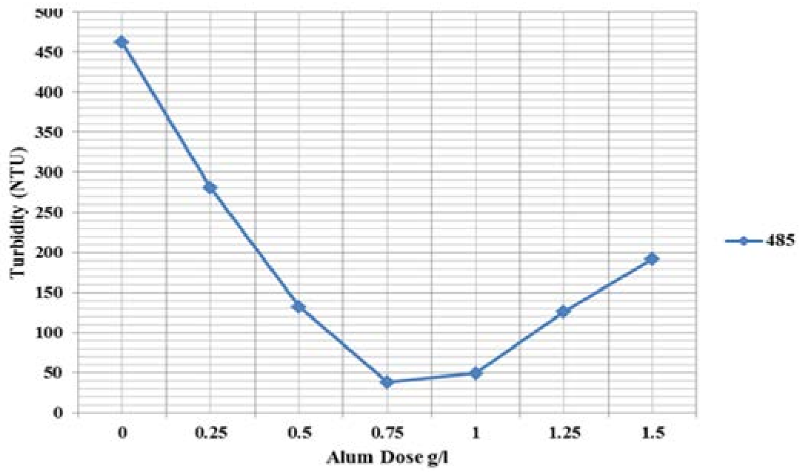

Figure 7b: Jar test result for imported sand from brazil

Appendix E

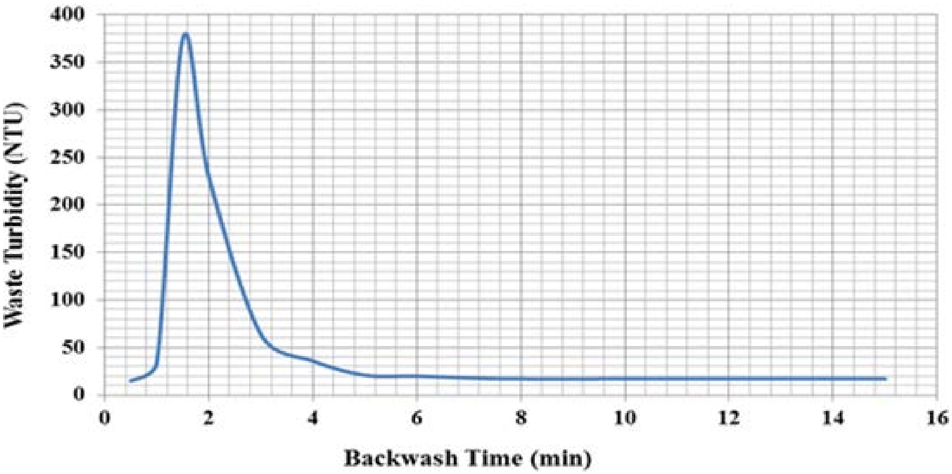

Figure 8: River benue sand bed expansion at 25.8 %, Backwash rate = 45.9 m/hr

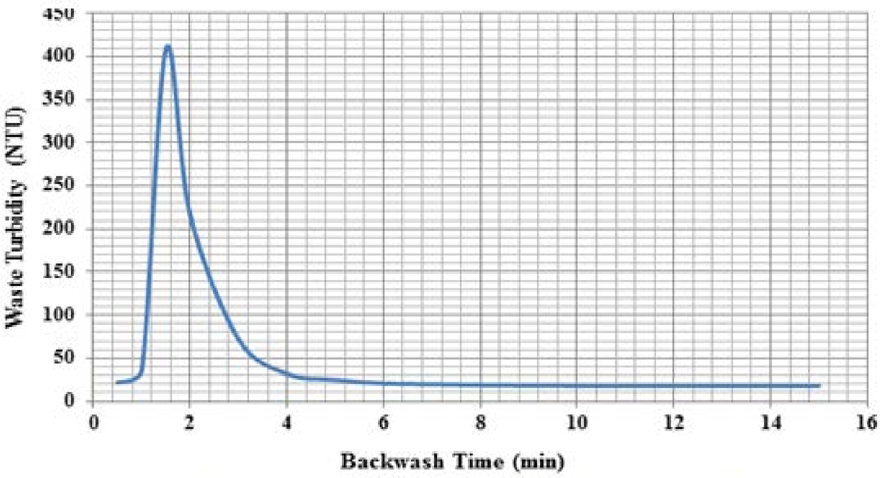

Figure 9: River asa sand bed expansion at 56.6 %, Backwash rate = 45.9 m/hr

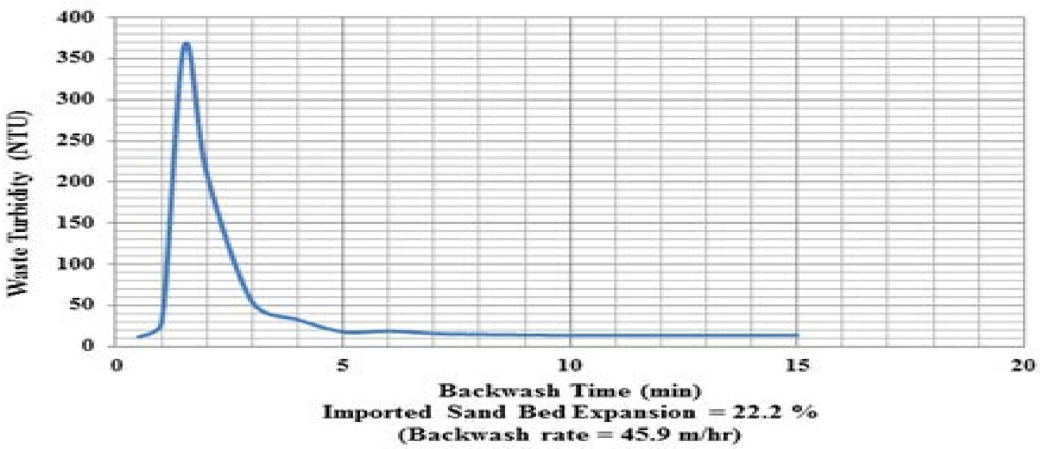

Figure 10: Imported sand bed expansion

Appendix F

River Sands	Effective Sizes (mm)	Uniformity Coefficient (U_c)	Acid Solubility (%)	Specific Gravity	Porosity (%)	Permeability (cm/sec)
River Benue Sand	0.35	1.43	1.05	2.67	42	4.7×10^{-1}
River Asa Sand	0.40	1.25	2.10	2.29	51	1.06
Imported Sand	0.46	1.48	0.85	2.60	45	3.5×10^{-1}
Recommended	**0.35 -1.00**	**1.3 - 1.8**	**< 2**	**>2.5**	**35 - 50**	$\mathbf{10^{-1} - 10^{-3}}$

Appendix G

Table G: Summary table of filtration tests (Head Loss Development, (cm))

River Sands	Rate = 6.45 m/hr, Run Time = 16 hrs	Rate = 9.65 m/hr, Run Time = 13 hrs
River Benue Sand	11.294	14.467
River Asa Sand	19.014	24.347
Imported Sand	11.281	14.454

Appendix H

Table H: Summary table of filtrate quality (Filtrate Turbidity, (NTU))

Inflow turbidity = 32 NTU

River Sands	Rate = 6.45m/hr, Run Time = 16hrs	Rate = 9.65m/hr, Run Time = 13hrs
River Benue Sand	2.01	2.79
River Asa Sand	5.09	5.87
Imported Sand	1.13	2.12

Appendix I

Table I1: Percentage turbidity removal through media with time for river benue sand.

(Filtration rate = 6.45 m/hr, Inflow turbidity = 32 NTU)

Depth(cm) /Time(hr)	5	15	30	45	60	75	90	105	120
1	36.19	50.66	62.75	72.03	78.69	83.75	88.09	91.03	93.63
2	38.56	52.50	64.38	73.25	79.81	84.88	88.56	91.41	93.75
3	40.53	54.00	65.47	74.13	80.66	85.38	88.94	91.78	93.81
4	42.44	55.34	66.47	74.88	81.16	85.72	89.31	92.00	93.88
5	44.22	56.72	67.44	75.59	81.66	86.22	89.69	92.16	94.00
6	46.09	58.06	68.44	76.34	82.28	86.59	89.94	92.41	94.06
7	48.31	60.28	69.91	77.22	83.13	87.34	90.44	92.78	94.13
8	50.03	61.53	71.16	78.31	83.75	87.72	90.78	93.03	94.25
9	52.25	63.50	72.50	79.06	84.50	88.31	91.28	93.38	94.38
10	54.25	64.25	73.13	79.81	84.88	88.69	91.41	93.63	94.50
11	54.50	64.13	73.25	79.97	85.13	89.66	91.69	93.88	94.56
12	54.66	64.19	73.41	80.13	85.28	89.81	91.84	94.19	94.63
13	54.81	64.25	73.56	80.28	85.44	89.97	92.06	94.16	94.66
14	53.28	62.59	71.75	78.94	84.13	88.13	91.16	93.44	94.22
15	51.81	61.59	71.13	78.50	83.75	87.75	90.88	93.13	94.00
16	50.28	60.94	70.41	78.00	83.50	87.63	90.66	92.94	**93.72**

Table I 2: Percentage Turbidity removal through media with time for River Benue Sand

(Filtration Rate = 9.65 m/hr; Inflow Turbidity = 32 NTU)

Depth(cm/ Time(hr)	5	15	30	45	60	75	90	105	120
1	34.84	48.81	60.91	70.16	76.84	81.91	86.22	88.63	91.91
2	37.94	50.66	62.50	71.41	77.94	82.78	86.72	89.56	92.16
3	39.41	52.63	63.63	72.28	78.81	83.50	87.09	89.94	92.28
4	42.00	53.50	64.63	73.00	79.81	83.88	87.47	90.19	92.53
5	43.50	54.84	65.72	73.88	80.28	84.50	87.97	90.44	92.78
6	45.59	56.47	67.09	74.50	80.66	84.75	88.31	90.91	93.03
7	47.56	58.56	68.56	75.59	81.28	85.50	88.69	91.28	93.16
8	49.41	60.16	69.69	76.47	82.03	85.97	88.94	91.53	93.28
9	48.09	58.72	68.97	76.28	82.03	85.81	88.88	91.25	92.75
10	46.69	57.19	67.84	75.66	81.66	85.69	88.66	90.88	92.38
11	45.88	56.97	67.75	75.16	80.41	84.69	87.81	90.28	91.91
12	44.43	55.88	66.31	74.88	80.09	84.19	87.66	90.09	91.81
13	44.19	54.78	66.78	74.44	79.97	83.81	87.50	89.84	**91.28**

Table I5: Percentage Turbidity removal through media with time for River Asa Sand.

(Filtration Rate = 6.45 m/hr ; Inflow Turbidity = 32 NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	26.56	41.03	53.13	62.41	69.06	74.13	78.47	81.41	84.00
2	28.94	42.88	54.75	63.63	70.19	75.25	78.94	81.78	84.12
3	30.91	44.38	55.84	64.50	71.03	75.75	79.31	82.16	84.19
4	32.81	45.72	56.84	65.25	71.53	76.09	79.69	82.38	84.25
5	34.59	47.09	57.81	65.97	72.03	76.59	80.06	82.53	84.38
6	36.47	48.44	58.81	66.72	72.66	76.97	80.31	82.78	84.44
7	38.69	50.66	60.28	67.59	73.50	77.72	80.81	83.16	84.50
8	40.41	51.91	61.53	68.69	74.13	78.09	81.16	83.41	84.63
9	42.63	53.88	62.88	69.44	74.88	78.69	81.66	83.75	84.75
10	44.63	54.63	63.50	70.19	75.25	79.06	81.78	84.00	84.88
11	44.88	54.50	63.63	70.34	75.50	80.03	82.06	84.25	84.94
12	45.03	54.56	63.78	70.50	75.66	80.19	82.22	84.56	85.00
13	45.19	54.63	63.94	70.66	75.81	80.34	82.44	84.53	85.03
14	43.66	52.97	62.13	69.31	74.50	78.50	81.53	83.81	84.59
15	42.19	51.97	61.50	68.88	74.13	78.13	81.25	83.50	84.38
16	40.66	51.31	60.78	68.38	73.88	78.00	81.03	83.31	**84.09**

Table I6: Percentage Turbidity removal through media with time for River Asa Sand.

(Filtration Rate = 9.65 m/hr ; Inflow Turbidity = 32 NTU)

Depth(cm)/ Time(hr)	5	15	30	45	60	75	90	105	120
1	25.22	39.19	51.28	60.53	67.22	72.28	76.59	79.00	82.28
2	28.31	41.03	52.88	61.78	68.31	73.16	77.09	79.94	82.53
3	29.78	43.00	54.00	62.66	69.19	73.88	77.47	80.31	82.66
4	32.38	43.88	55.00	63.38	70.19	74.25	77.84	80.56	82.91
5	33.88	45.22	56.09	64.25	70.66	74.88	78.34	80.81	83.16
6	35.97	46.84	57.47	64.88	71.03	75.13	78.69	81.28	83.41
7	37.94	48.94	58.94	65.97	71.66	75.88	79.06	81.66	83.53
8	39.78	50.53	60.06	66.84	72.41	76.34	79.31	81.91	83.66
9	38.47	49.09	59.34	66.66	72.41	76.19	79.25	81.63	83.13
10	37.06	47.56	58.22	66.03	72.03	76.06	79.03	81.25	82.75
11	36.25	47.34	58.13	65.53	70.78	75.06	78.19	80.66	82.28
12	34.81	46.25	56.69	65.25	70.47	74.56	78.03	80.47	82.19
13	34.56	45.16	57.16	64.81	70.34	74.19	77.88	80.22	**81.66**

Table I7: Percentage Turbidity removal through media with time for Imported Sand

(Filtration Rate = 6.45 m/hr; Inflow Turbidity = 38 NTU)

Depth(cm) /Time(hr)	5	15	30	45	60	75	90	105	120
1	48.58	60.76	70.95	78.76	84.37	88.63	92.29	94.76	96.95
2	50.58	62.32	72.32	79.79	85.32	89.58	92.68	95.08	97.05
3	52.24	63.58	73.24	80.53	86.03	90.00	93.00	95.39	97.11
4	53.84	64.71	74.08	81.16	86.45	90.29	93.32	95.58	97.16
5	55.34	65.87	74.89	81.76	86.87	90.71	93.63	95.71	97.26
6	56.92	67.00	75.74	82.39	87.39	91.03	93.84	95.92	97.32
7	58.79	68.87	76.97	83.13	88.11	91.66	94.26	96.24	97.37
8	60.24	69.92	78.03	84.05	88.63	91.97	94.55	96.45	97.47
9	62.11	71.58	79.16	84.68	89.26	92.47	94.97	96.74	97.58
10	63.79	72.21	79.68	85.32	89.58	92.79	95.08	96.95	97.68
11	64.00	72.11	79.79	85.45	89.79	93.61	95.32	97.16	97.74
12	64.13	72.16	79.92	85.58	89.92	93.74	95.45	97.42	97.79
13	64.26	72.21	80.05	85.71	90.05	93.87	95.63	97.39	97.82
14	62.97	70.82	78.53	84.58	88.95	92.32	94.87	96.79	97.45
15	61.74	69.97	78.00	84.21	88.63	92.00	94.63	96.53	97.26
16	60.45	69.42	77.39	83.79	88.42	91.89	94.45	96.37	**97.03**

Table I8: Percentage Turbidity removal through media with time for Imported Sand.

(Filtration Rate = 9.65 m/hr; Inflow Turbidity = 38 NTU)

Depth(cm) /Time(hr)	5	15	30	45	60	75	90	105	120
1	46.89	58.66	68.84	76.63	82.26	86.53	90.16	92.18	94.95
2	49.50	60.21	70.18	77.68	83.18	87.26	90.58	92.97	95.16
3	50.74	61.87	71.13	78.42	83.92	87.87	90.89	93.29	95.26
4	52.92	62.61	71.97	79.03	84.76	88.18	91.21	93.50	95.47
5	54.18	63.74	72.89	79.76	85.16	88.71	91.63	93.71	95.68
6	55.95	65.11	74.05	80.29	85.47	88.92	91.92	94.11	95.89
7	57.61	66.87	75.29	81.21	86.00	89.55	92.24	94.42	96.00
8	59.16	68.21	76.24	81.95	86.63	89.95	92.45	94.63	96.11
9	58.05	67.00	75.63	81.79	86.63	89.82	92.39	94.39	95.66
10	56.87	65.71	74.68	81.26	86.32	89.71	92.21	94.08	95.34
11	56.18	65.53	74.61	80.84	85.26	88.87	91.50	93.58	94.95
12	54.97	64.61	73.39	80.61	85.00	88.45	91.37	93.42	94.87
13	54.76	63.68	73.79	80.24	84.89	88.13	91.24	93.21	**94.42**